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OBSERVATIONS OF THE DEVELOPMENT OF STRIATIONS IN LARGE BARIUM ION CLOUDS

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Alaska University

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PROJECT SECEDE

OBSERVATIONS OF THE DEVELOPMENT OF STRIATIONS IN LARGE BARIUM ION CLOUDS

University of Alaska, Geophysical Inst.

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IN LARGE BARIUM ION CLOUDS

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ABSTRACT

Striations develop within large (12-352 kg releases) barium ion clouds in a two-stage process. First the clouds split into sheets commencing at the trailing edge of the cloud. Then distortions or pinching effects within the individual sheets cause the formation of field-aligned raylike structures. In the clouds observed, the individual sheets were 200 m to 1000 m in thickness and were spaced 700 m to 2000 m apart. Quasi-sinusoidal waviness or spatially periodic thickenings exhibited a wavelength typically 700 m to 1000 m. When rod-like structures appeared, these were typically 200 m to 400 m in diameter and were spaced along the pre-existing sheet at 700 m to 1000 m on centers.

In the course of experiments performed by various groups during the past few years more than one hundred barium releases have been performed in the ionosphere. A listing of many of these is given by Davis and Wallis (1972). Most of the ion clouds produced have been observed to develop striations. The objective of most releases has been to measure the ambient electric field through observation of the motion of an ion cloud. The velocity of the cloud in the plane normal to the ambient magnetic field $\vec{B}$ is given approximately by the equation (Haser, 1967)

$$V_{\perp} = \frac{1}{K}\,\frac{2}{1+\lambda^*}\,\frac{\vec{E}_{\perp}}{B} + \frac{\vec{V}_n \times \vec{B}}{B} + \frac{2}{1+\lambda^*}\,\frac{\vec{E}_{\perp} \times \vec{B}}{B^2} + 1 - \frac{2}{1+\lambda^*}\,V_n \tag{1}$$

Where $\vec{V}_n$ is the motion of the neutral cloud, K is the ratio of the ion-neutral collision frequency ν to the ion gyrofrequency ω and λ^* is the ratio of the Pederson conductivity inside the cloud to that outside. By releasing cannisters containing 1 to 3 kg of a Ba-CuO mixture at altitudes above 200 km, the attempt is made to keep $\lambda^* \stackrel{\sim}{\sim} 1$ and K large so that Equation 1 reduces to

$$V_{\perp} = \frac{\vec{E}_{\perp} \times \vec{B}}{B^2} \tag{2}$$

That is, the medium is perturbed as little as possible so that the barium ions take on the role of tracers of charged particle motion under the influence of the crossed ambient electric and magnetic fields. In this case, the development of striations may be the result of natural inhomogeneities in the ionosphere or the development may be caused by the cloud itself. Volk and Haerendel (1971) have given a partial theoretical treatment of this problem and have concluded that striations of very small transverse scale lengths can be produced by the cloud itself. Linson and

Workman (1970) have examined a low-frequency 'Gradient drift' instability mechanism whereby the striations are caused by the cloud rather than by natural inhomogeneities. They conclude that it is likely that both the cloud and the natural inhomogeneities contribute to development of striations.

A description of striation formation in a small (2.4 kg) cloud released at 194 km over Eglin Air Force Base, Florida was given by Rosenberg (1971). At about 500 sec after release the ion cloud developed three sheet-like striations which became approximately 10 km long, 30 km high and 0.6 km in thickness by 930 sec after release.

Where we describe observations of the motions and striation developments within very large barium clouds released as part of the SECEDE program sponsored by the Advanced Research Projects Agency both in the auroral zone at College, Alaska, and at middle latitude at Eglin Air Force Base, Florida and in Puerto Rico. The releases discussed here ranged in size from 16 kg to 320 kg to Ba-CuO mixture and were performed at altitudes ranging from 140 km to 250 km. Environmental conditions ranged from magnetically quiet to very disturbed (in the case of certain of the auroral zone releases). At least in a qualitative sense the striation developments were similar to those in the small cloud described by Rosenberg. However, owing to the large size and low altitude of these releases, it seems likely that the formation of striations must be greatly influenced by the clouds themselves.

OBSERVATIONS

Barium releases A and D listed in Table I were performed just off the northern coast of Puerto Rico near the position 18° 61' N, 66° 74' W. The observations reported here were obtained primarily from photographic cameras and television systems carried aboard two jet aircraft. One aircraft flew eastward in an arcing trajectory located within 100 km of

the intersection with the earth's surface of the geomagnetic field line on which the release was made. The other aircraft flew northward along a path approximately 400 km eastward of the sub-release point. On this aircraft the television system had a field of view of 6° by 8°, whereas on the other aircraft the television field of view was 12° by 16°.

Barium releases E through J (see Table I) were performed in Alaska near the position 65° N, 150° W, which is located approximately midway along the line extending from College magnetically northward 250 km to Fort Yukon. At each of these two observing locations were all-sky cameras, arrays of photographic cameras with fields of view near 50° and television cameras with fields of view 12° by 16°. At Tok and Bettles, located 310 km east and 260 km west of the College-Fort Yukon meridian, respectively, all-sky cameras and 50°-field photographic cameras were operated.

Clouds N, O, P, R, and S (see Table I) were released at a point just south of Eglin Air Force Base, Florida such that the projection of the magnetic field line on which the release occurred intersected the earth's surface at a location near one of our main observing stations, designated Site C-6. Other main optical observing locations were at Barin Field, Mississippi and Tyndall Air Force Survival School, Florida, respectively located approximately 150 km west and 100 km east of the sub-release point. At each of these three observing stations were operated all-sky cameras and also television cameras with 12° by 16° fields of view. A variety of photographic cameras was operated by various groups at these three stations and at several other locations as well.

In general, the all-sky and other photographic cameras used for these observations were each programmed to obtain several photographs per minute with exposure times of several seconds, depending upon the brightness of the sky background. Throughout all the release observations, the television

cameras recorded cloud images at the rate of 30 images per sec on photographic film and 60 images per sec on magnetic video tape.

dFor releases E through J, performed in Alaska, the television systems at College and Fort Yukon were linked to a computer to allow real-time triangulation of cloud position. Outputs of shaft encoders indicating the azimuth and elevation of each television view direction were fed to the computer. With a cycle time of 5 sec the computer calculated the midpoint of the shortest line between the two view directions (in general the two lines of sight did not intersect). This midpoint was assumed to be the triangulated position of the object being viewed. To aid in the evaluation of the quality of each triangulation the closure error was calculated. Also, the computer transmitted to the operator of each television system data enabling him to re-orient to the triangulated position. With these data and the ability to maintain voice communications between them, the television operators could locate a specific point within a barium ion cloud with a precision of order 100 m.

A similar tracking system was used in Florida to observe releases N, O, P, R and S. It was modified to allow inputs from the three ground-based television systems deployed there and was upgraded to allow a cycle time of 1 sec.

REDUCTION OF OBSERVATIONS

The objectives of the photographic and television observations were to determine the morphological developments within the barium neutral and ion clouds. Here we describe the reductions only of those data pertinent to the main subject of this paper, the development of striations. Such pertinent data include that on motion of the neutral cloud, gross motion of the barium ion cloud and of various portions of the cloud, the formation of these mappings onto a plane normal to the direction of the magnetic

field is accomplished by altering the meridional distance scale as shown on the diagrams. In Fig. 1 the light dashed lines show the approximate outlines of a diffuse ion glow surrounding the structured portion of the ion cloud. The first mapping in Fig. 1, at 2334:56, 16 sec after release, shows the cloud to be roughly circular in the horizontal plane. The ion cloud soon elongated in the direction of the neutral wind (eastward). Within 2 minutes, the trailing edge splits into two field-aligned sheets with a definite cleft between; these are labeled B and C in the mapping for 2336:39 and in subsequent mappings. During the next minute the southern limb of the trailing edge splits again and a portion pinches off. At 2339:17 the trailing edge of the cloud reached the magnetic zenith of Site C-6 and at this time accurate measurements of the dimensions of the striation features can be made. The three field-aligned sheet structures are each near 200 m thick and are spaced approximately 700 m on centers. The two rod-like structures of the southern sheet have centers approximately 100 m apart. Subsequent mappings of Fig. 1 show a continued east-west growth of the sheet structures within each sheet. Also, the growth of new sheets emanating from the south limb of the ion cloud is observed. These start as small buds on the side of the cloud, they grow into hook-like structures which finally become more sheet-like as time progresses.

A somewhat similar development was observed in the ion cloud from release S but the growth of the striated structure was somewhat slower. The mappings on a horizontal place are shown in Fig. 2. Over a period of 10 minutes the cross-sectional shape of the ion cloud changes from circular to elongate in the direction of the neutral wind. At the trailing edge the density profile steepens, and by 00:01:11, two distinct lobes form. In the following minutes two sheets develop, and the southern sheet

level of geomagnetic disturbance as measured by ground-based magnetometers, and the time-varying morphology of the ion cloud as striations develop. Except in one case (Release F) where large wind shears caused considerable distortion, the barium neutral clouds remained roughly spherical. In these cases the neutral cloud was approximated by a sphere and triangulations were performed using the all-sky camera photographs. In some instances, cross-checks were available from the television observations and agreement between the two methods was found. In general, the luminosity distribution over the apparent surface of each neutral cloud was not symmetrical about the cloud center, indicating a non-symmetrical volume emission and perhaps also departure from the assumed spherical shape. Owing largely to this asymmetry, we estimate a possible error of 10% in the mean drift speeds obtained for the neutral cloud motion.

Owing to the favorable geometry of the cloud motion relative to the observing stations, the real-time tracking data was found to be adequate for determination of the gross motion of the ion clouds of the Alaska release series, releases E through J. However, for the Florida releases, the real-time tracking data were inadequate and it was necessary to perform triangulations using the recorded television data. Using 2 or more stations, triangulations were performed on specific points within the barium ion clouds, usually the tops and bottoms of striations that could be identified from more than one station. In this way the altitudes of the tops and bottoms of the ion clouds and the areal positions of the clouds could be found at several times in the release history. These measurements allowed determination of the vertical and horizontal cloud motions. Detailed mapping of the striation development was performed using photographs from Site C-6 when the station was located near the magnetic field line occupied

by the cloud. These one-station detail mappings required the use of the cloud altitude as determined by 2-station triangulation. In the preparation of these detail mappings, it was assumed that the bottom of a particular cloud was everywhere at a constant altitude at a particular time. Minor errors resulted as a consequence of this assumption. More serious were errors in the interpretation of which parts of the cloud images corresponded to the bottoms of the cloud structure; only at those points exactly in the magnetic zenith was interpretation unnecessary. Through the use of several individuals in the interpretation we have attempted to minimize error. Yet every mapping prepared does contain at least minor errors. However these errors do not obscure the configuration, dimensions and developments of the striation structures. Errors in dimensions determined from the mappings are mostly less than 10% and rarely greater than 20%.

Observations taken with ground-based magnetometers near each release area were reduced using baselines determined from quiet days before, during and after each release series.

NEUTRAL CLOUD MOTIONS

At low latitude, or even at auroral latitudes during times of low disturbance, the motion of the neutral atmosphere relative to the earth's surface may have more influence upon the morphological development of a barium ion cloud than a weak ambient electric field. Table II presents average speeds and directions of horizontal motions and vertical speeds of the neutral clouds resulting from the releases listed in Table I. The average values given there represent measurements made over the first 10 to 25 min of the neutral cloud history. These measurements show that the neutral cloud takes up the horizontal motion of the ambient neutral wind within 1 to 2 min.

The two morning releases (A and D) near latitude 19° N showed the existence of generally westward-directed winds near altitude 180 km. The five evening releases (N, O, P, R, S) made near 29° N at altitudes 144 km to 257 km all indicated generally eastward-directed winds. A less systematic wind pattern is indicated by the auroral zone releases (E through J); evidently the high-altitude wind there is influenced by the disturbance environment.

ION CLOUD MOTIONS

Description of the motion of the ion clouds resulting from these large releases is more complex than that of the neutral clouds because of horizontal spreading of the ion clouds. In describing the ion cloud motion and morphological development it is convenient to adopt a terminology referenced to the neutral wind instead of to the earth's surface. That edge of the ion cloud horizontally most removed from the neutral cloud is called here the "leading edge". Thus, in a reference frame fixed to the neutral atmosphere at release altitude, the leading edge of the ion cloud appears to have the highest horizontal speed. Similarly, that edge of the ion cloud nearest the neutral cloud is called the "trailing edge". This terminology is particularly useful because of two observed characteristics of the large ion clouds described here. Firstly, the ion clouds all developed horizontal elongation between the leading and trailing edges. Secondly, without observed exception, the morphological development of striated structure within the large ion cloud develops first at the trailing edge. However, this terminology is a bit awkward to the earth-bound observer because, relative to his position, the trailing edge sometimes moves faster than the leading edge.

The observed ion cloud motions are summarized in Table II. Qualitatively, the ion motions observed during each of these release experiments can be described as approximating one of two extreme cases:

Case I - Weak or near-zero ambient electric field transverse to $\vec{B}$. In this case the leading edge of the ion cloud remains at or near the initial release point. Relative to the earth's surface the trailing edge of the ion cloud is seen to move approximately in the direction of the neutral cloud at a speed 1/2 to 3/4 as large. Thus the ion cloud elongates in the direction of the horizontal neutral wind.

Case II - Relatively large transverse electric field. The leading edge of the ion cloud rapidly moves away from the neutral cloud approximately in the direction of the horizontal component of $\vec{E} \times \vec{B}$, as does the trailing edge, but at somewhat lower speed. The ion cloud elongates horizontally in the direction $\vec{E} \times \vec{B}$.

Of the ion cloud motions listed in Table II, clouds A, D, G, N, O, P, R and S approximate Case I whereas cloud F is an example of Case II. Others listed are intermediate, their motion clearly is influenced both by the neutral wind and the transverse electric field.

DEVELOPMENT OF STRIATIONS

Of the 13 barium clouds listed in Table I only several were observed from locations sufficiently well-placed to allow detailed observation of the development of striations. Owing to the rapid diffusion of barium ions along the direction of the local magnetic field, the ion clouds become elongated soon after release. Consequently the striation development is normally obscured unless observation can be performed along the direction of the magnetic field. Several of the clouds released from Eglin (clouds N through S) were favorably located relative to one of our observing sites, Site C-6. Using observations primarily from that site, we describe

here in detail the development of striations within three ion clouds.

The simplest striation developments occurred in the ion cloud from release N, a 48 kg release performed at altitude 144 km (see Table I). Figure 1 shows mappings of the ion cloud on a horizontal plane. A transformation of these mappings onto a plane normal to the direction of the magnetic field is accomplished by altering the meridional distance scale as shown on the diagrams. In Fig. 1 the light dashed lines show the approximate outlines of a diffuse ion glow surrounding the structured portion of the ion cloud also visible in the accompanying photograph, Fig. 2. The first mapping in Fig. 1, at 2334:56, 16 sec after release, shows the cloud to be roughly circular in the horizontal plane. The ion cloud soon elongated in the direction of the neutral wind (eastward). Within 2 minutes, the trailing edge splits into two field-aligned sheets with a definite cleft between; these are labeled B and C in the mapping for 2336:39 and in subsequent mappings. During the next minute the southern limb of the trailing edge splits again and a portion pinches off. At 2339:17 the trailing edge of the cloud reached the magnetic zenith of Site C-6 and at this time accurate measurements of the dimensions of the striation features can be made. The three field-aligned sheet structures are each near 200 m thick and are spaced approximately 700 m on centers. The two rod-like structures of the southern sheet have centers approximately 1000 m apart. Subsequent mappings of Fig. 1 show a continued east-west growth of the sheet structures within each sheet. Also, the growth of new sheets emanating from the south limb of the ion cloud is observed. These start as small buds on the side of the cloud, they grow into hook-like structures which finally become more sheet-like as time progresses.

A somewhat similar development was observed in the ion cloud from release S but the growth of the striated structure was somewhat slower. The

mappings on a horizontal plane are shown in Fig. 3. Over a period of 10 minutes the cross-sectional shape of the ion cloud changes from circular to elongate in the direction of the neutral wind. At the trailing edge the density profile steepens, and by 00:01:11, two distinct lobes form. In the following minutes two sheets develop and the southern sheet develops into two separate sheets which break up into rod structures. The northern sheet shows a slower development; within it, signs of spatially periodic bunching or folding of the sheet appear in the mappings at 0010:20 to 0012:29. At the same time this sheet splits into two other sheets, that splitting proceeds from the trailing edge toward the leading edge. Finally, by 0014:31, the sheet-like structures are spaced approximately 2 km on centers. The sheets are 200-400 m in thickness. Rod-like structures within the sheets are approximately 300 m in diameter and are spaced 700-800 m apart on centers.

Release R, performed at altitude 252 km, exhibited a somewhat different development in the striation structure as compared to releases S and N. During the first minutes after release the ion cloud retained an approximately circular cross-section that later became distorted in a complex way and did not become as horizontally elongated as the ion clouds of the S and N releases. The high optical density of the cloud obscured the details of this distortion and so only that portion where striations developed are shown in the mappings of Fig. 3. The first sign of striation development was the appearance of a dense protuberance on the northeast edge of the cloud, as is shown on the mapping at 0011:55, nearly 20 min after release. Initially nearly 3 km across, this feature became thinner and extended out in the direction of the neutral wind to form a sheet approximately 400 m thick. Within 2 min additional irregularities in the eastern edge of the cloud develop (0013:01). These become more sheet-like and

some undergo splitting until an extended series of nearly parallel sheets has evolved. Compared to the sheets resulting from clouds S and N, the sheets in cloud R do not show much of a development into rows of rods, although, at a later time, after 0017:21, the photographs of the cloud show evidence of a field-aligned filamentary character within the sheets. The portion of the R ion cloud showing striation development was approximately 15 km across; individual sheets were 200 m to 1000 m in thickness and were spaced 700 to 2000 m apart. Quasi-sinusoidal irregularities along the sheets had a wavelength of 700 to 1000 m.

Observations of striation developments in the other clouds listed in Table 1 are compatible with the descriptions given above for clouds N, R and S, although in some cases few useful observations are available. Of the auroral zone releases, only the G release could be examined carefully. Its striation development was similar to that observed during release N. Owing to its very large size, 352 kg, release O is of special interest. From an initial circular cross-section, the ion cloud spread to the east in the direction of the neutral wind was moving. By 20 min after release the ion cloud appeared to be in the form of a single homogeneous sheet several kilometers thick extending in the east-west direction. Shortly thereafter, the sun set on the cloud preventing further optical observation, but in the last minutes it was possible to recognize that the trailing (eastern) edge of the cloud was splitting into several thin sheets.

Though the details of the morphological developments differ from cloud to cloud, there are sufficient similarities to enable a single generalized description of striation growth in the large barium clouds observed. Soon after release the barium ion cloud forms and expands parallel to the magnetic field to develop a cigar-shape several kilometers in diameter

are 20 km to 60 km in length. The ion cloud is then observed to elongate laterally in a direction determined by the transverse electric field and the neutral wind. At low and middle latitude, where the transverse field normally is weak, the lateral elongation of the ion cloud is approximately in the direction the neutral wind is moving. If the transverse electric field is large, the ion cloud elongates in the direction $\vec{E} \times \vec{B}$. It appears that ion clouds released at relatively low altitude (< 200 km) tend to elongate laterally more than those at higher altitude.

Prior to the formation of striated structure, the trailing edge of the ion cloud (edge nearest the neutral cloud and the slowest moving in the reference frame fixed to the ambient neutral atmosphere) develops a steep density profile. It appears that the barium ion density increases near the trailing edge relative to the density elsewhere in the cloud. A quantitative estimate of the apparent increase in density is difficult owing to the large optical thickness of the cloud.

Subsequent to a steepening of the density profile at the trailing edge of the ion cloud, this portion of the cloud separates into two or more sheets of thicknesses near 200 m and typically spaced near 1000 m apart. These sheets may subdivide and additional sheets may grow along the flanks of the cloud. In some clouds as many as 15 parallel sheets have been observed. At the time when these sheets are observed to form, there usually is a change in the speed and direction of motion of the trailing edge of the ion cloud. Considering Eq. 1, this change suggests that the formation into sheets involves localized increase of barium ion density within each sheet, that is, the ion density within the sheets appears to be higher than the density in the homogeneous ion cloud prior to sheet formation. The growth of sheets in large clouds invariably begins at the trailing edge and proceeds toward the leading edge of the ion

cloud. Eventually the entire ion cloud may be in the form of multiple sheets, especially if the horizontal cloud velocity is high, as is often the case at the auroral zone.

Subsequent to their formation the individual barium ion sheets develop irregularities of various sorts. Quasi-sinusoidal waviness or periodic thickenings appear within the sheets, the wavelength being typically 700 m to 1000 m. A sheet may separate into an array of field-aligned rods 200-400 m in diameter and spaced approximately 700 m to 1000 m on centers. In some instances a smaller-scale filamentary structure has been observed with diameters of identifiable filaments as small as 20 m (Boquist, 1971). The temporal scale of the striation developments is quite variable. The sequence of developments described above has been observed in one case to occur in a time less than 5 sec (Release F) and in others to be incomplete after 20 min. Table III contains a listing of the times of the various developments in those cases where adequate observations are available. From the values listed in Table III there is an indication that the time to develop striated structure is inversely related to the speed of the ion cloud. Other factors probably influencing this time scale are the release size and the release altitude. Also it appears that there is some tendency for the striation developments to occur more rapidly when the ambient magnetic field is undergoing fluctuation. We have investigated this point in some detail and have noticed that any tendency for the time of striation development within large barium ion clouds to depend upon magnetic fluctuations does not extend to small barium releases ($\leq$ 3 kg) performed at altitudes above 190 km.

DICCUSSION

The ion clouds resulting from large (> 6 kg) barium releases have

been observed to evolve into field-aligned sheet structures which then may become somewhat contorted and may break up into rod-like and smaller-scale filamentary structures aligned along the magnetic field. These combined developments give the barium ion cloud the appearance of being "striated" when viewed at an angle to the local magnetic field. Observers evidently have used the term striation to describe both the sheet and rod structures. Simultaneous observation from several stations reveals that the appearance of a striated barium cloud depends markedly upon the viewing angle relative to the direction of the magnetic field. Details of the striation development generally are obscured unless the view is along the magnetic field direction.

It appears that there are two distinctive physical processes involved in the growth of striations. One is responsible for the separation of the ion cloud into sheets, and a separate process, perhaps involving a shear instability, may cause the sheets to develop into rods or other field-aligned structures. Thome (1969) has noted that the HF doppler radar spectrum of a cloud changes radically at a time most nearly associated with the time when the rod-like and filamentary structures form rather than with the time when sheets form.

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TABLE I

BARIUM RELEASE PARAMETERS

EVENT	UT DATE AND TIME	RELEASE SIZE, kg	RELEASE ALTITUDE, km	LOCATION (AND APPROX. RELEASE COORD.)	TWILIGHT
A(pple)	02 JUN 1968 091742	12	196	Puerto Rico (18.7N,66.8W)	Morning
D(ogwood)	12 JUN 1968 091042	12	188	Puerto Rico (18.7N,66.9W)	Morning
E(lm)	05 MAR 1969 043247	12	170	College	Evening
F(ir)	15 MAR 1969 050814	48	165	College	Evening
G(um)	19 MAR 1969 051915	48	168	College	Evening
H(emlock)	20 MAR 1969 053910	96	176	College	Evening
I(ronwood)	11 MAR 1969 1408	12	140	College	Morning, Pre-twilight
J(uniper)	4 MAR 1969 043224	6	170	College	Evening
N(utmeg)	16 JAN 1971 233440	48	144	Eglin	Evening
O(live)	29 JAN 1971 235357	352	190	Eglin	Evening
P(lum)	20 JAN 1971 234705	48	182	Eglin	Evening
R(edwood)	26 JAN 1971 235209	48	252	Eglin	Evening
S(pruce)	01 FEB 1971 235204	48	184	Eglin	Evening

TABLE II

CLOUD MOTION RELATIVE TO THE EARTH'S SURFACE

	Neutral Cloud Center			Ion Cloud			
				Leading Edge		Trailing Edge	
Release	Speed (m/s)	Direction (Deg.)	Fall Rate (m/s)	Speed (m/s)	Direction (Deg.)	Speed (m/s)	Direction (Deg.)
A	85	280	-	-	-	63	279
D	70	246	-	-	-	61	242
E	92	117	-	∿ 45	∿ 320	91	321
F	73	326	-	∿ 1100	∿ 315	1500	314
G	87	140	-	∿ 40	∿ 150	55	153
H	73	41	-	∿ 100	∿ 300	200	299
I	No observed neutral cloud		-	-	-	-	Diffused east and south
J	117	121	-	-	-	100	139
N	55	95 to 125	10 ± 3	10	173	36	111
O	79	83	13 ± 3	-	-	∿ 41	93
P	108	84	7 ± 3	-	-	∿ 60	∿ 90
R	93	83	48 ± 9	33	162	49/33	105/7
S	51	65 to 93	10 ± 3	32/26	165/72	25/33	105/7

TABLE III

TIME (IN SEC AFTER RELEASE) OF INTERNAL DEVELOPMENTS IN ION CLOUDS

Release	Steepening	Sheet Development	Fine Structure
A	-	476	-
D	-	720	-
E	-	-	94
F	-	-	< 5
G	-	-	213
H	-	-	95
I	-	-	-
J	-	-	58
N	< 120	120	338
O	840	< 900	1248
P	175	355	415
R	797	1080	1550
S	< 600	600	840

FIGURE CAPTIONS

Fig. 1 Mapping of the configuration of the trailing edge of the N(utmeg) ion cloud on a horizontal plane (left-hand ordinate scale) or on a plane perpendicular to the magnetic field direction (right-hand ordinate scale). Points A, B, C and D are identified to aid visualizing the cloud growth. The magnetic zenith position is indicated on each mapping. The dashed line indicates the approximate boundary of barium ion glow surrounding the central, discrete portion of the cloud.

Fig. 2 Mappings of the S(pruce) ion cloud; see also the caption for Fig. 1.

Fig. 3 Mappings of the trailing edge of the R(edwood) ion cloud; see also the caption for Fig. 1.

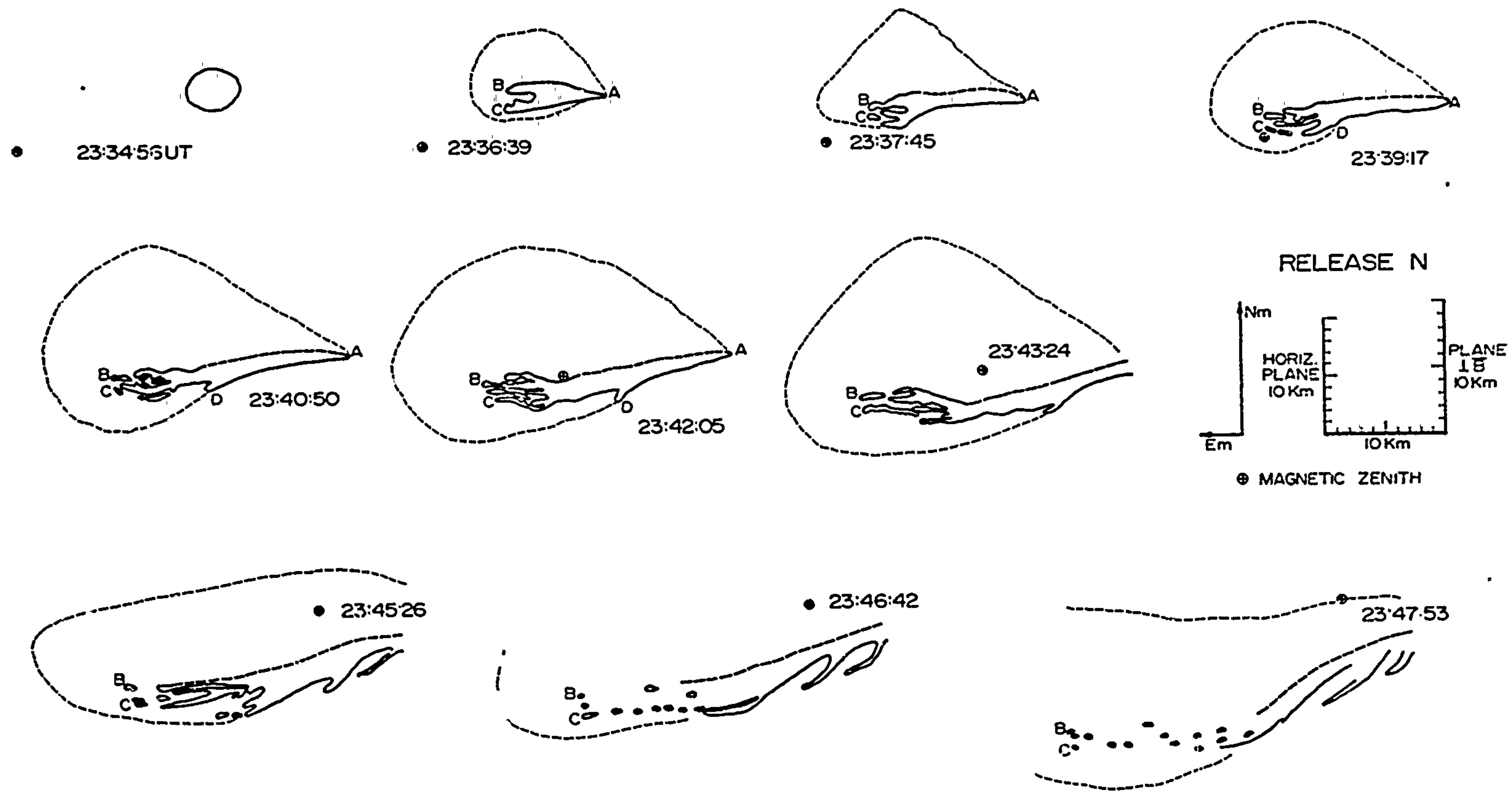
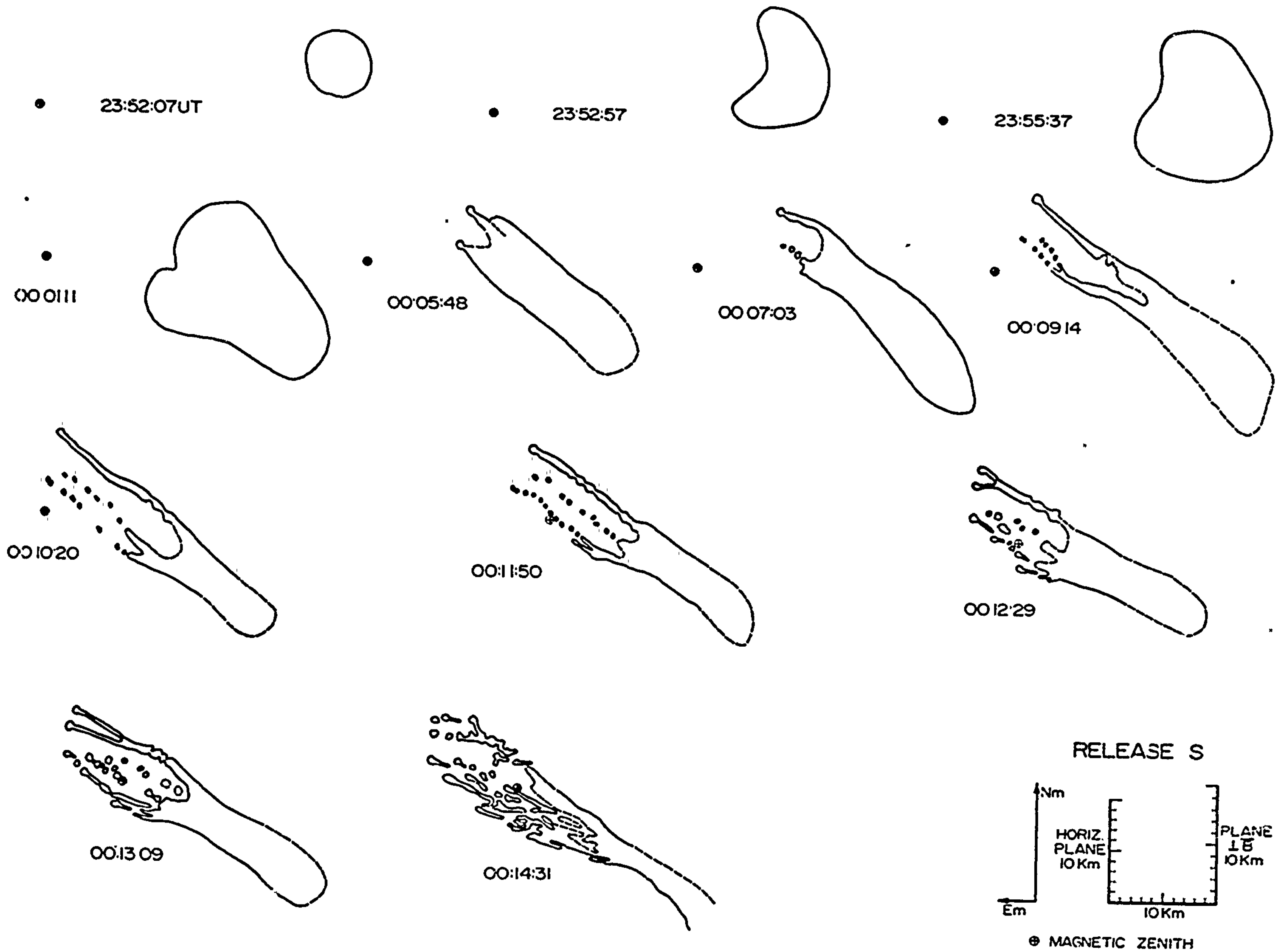

23:34:56UT
23:36:39
23:37:45
23:39:17
23:40:50
23:42:05
23:43:24
RELEASE N
Nm
Em
HORIZ. PLANE 10 Km
PLANE ⊥B 10Km
10 Km
⊕ MAGNETIC ZENITH
23:45:26
23:46:42
23:47:53
A
B
C
D

Fig. 1



23:52:07UT
23:52:57
23:55:37
00:01:11
00:05:48
00:07:03
00:09:14
00:10:20
00:11:50
00:12:29
00:13:09
00:14:31
RELEASE S
Nm
Em
HORIZ.
PLANE
10Km
PLANE
⊥B
10Km
10Km
⊕ MAGNETIC ZENITH

Fig.2

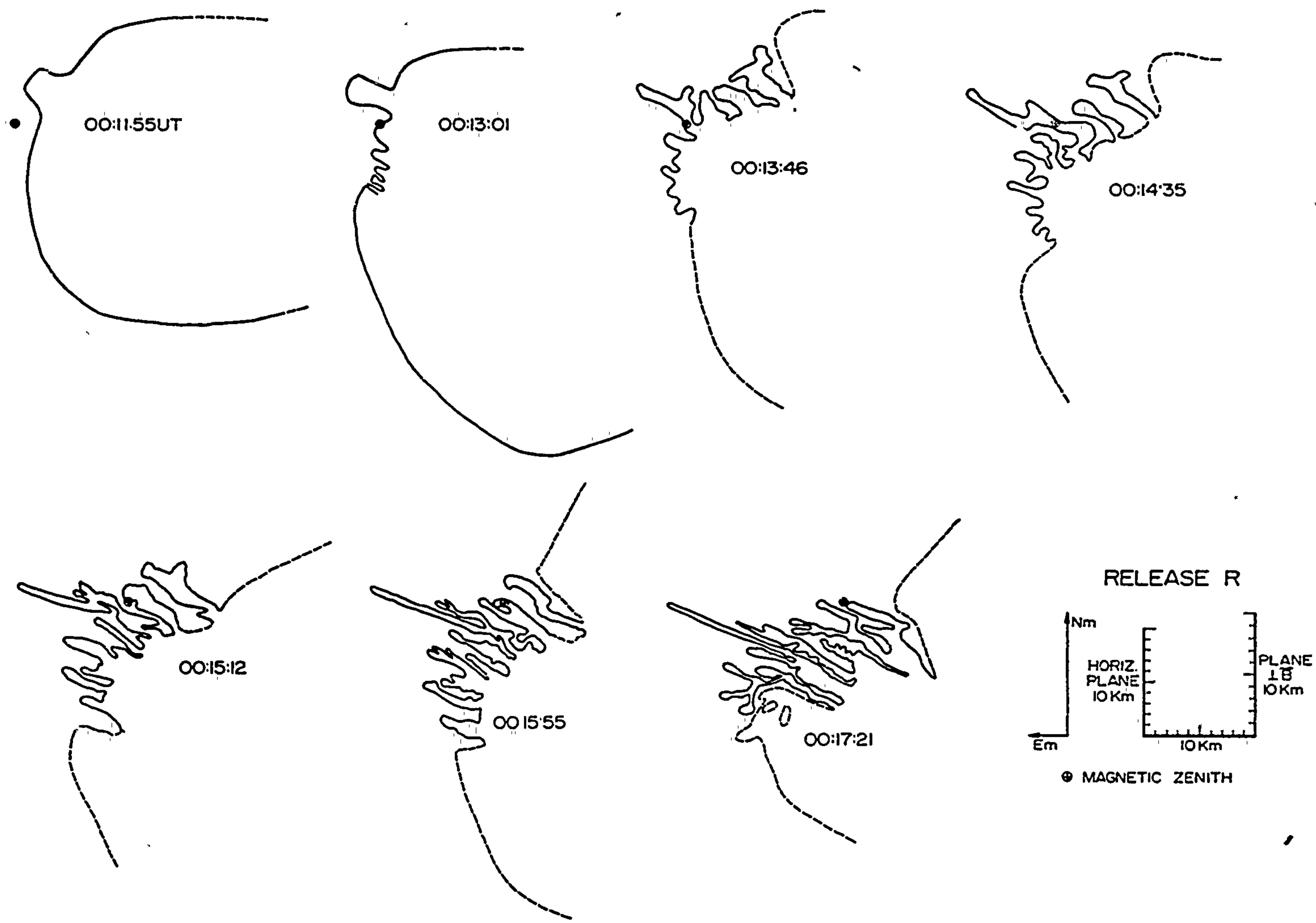

00:11:55UT
00:13:01
00:13:46
00:14:35
00:15:12
00:15:55
00:17:21
RELEASE R
Nm
HORIZ.
PLANE
10 Km
PLANE
⊥B
10 Km
Em
10 Km
⊕ MAGNETIC ZENITH

Fig.3